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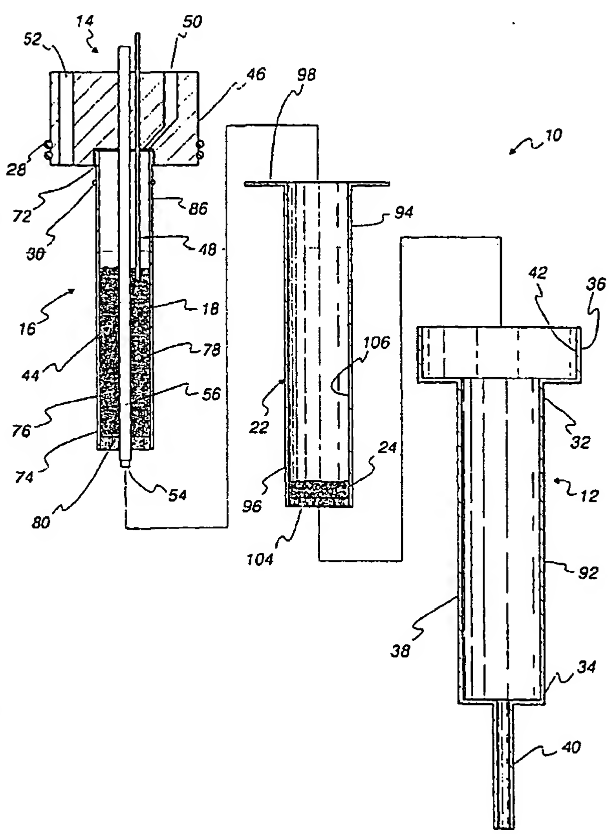
(54) Title: PROCESS FOR EVAPORATION AND PROCESS VESSEL WITH INTEGRAL EVAPORATOR



(57) Abstract: A process for evaporating a feed liquid and a process vessel (10) containing both an evaporation zone (18) for evaporating a liquid feed and a treatment zone (26) for treating the resulting vapor uses an evaporation surface (82) to prevent the formation of liquid droplets. The apparatus comprises an injector (48) having an orifice (66), the orifice (66) being in the evaporation zone (18), at least one evaporation surface (82) for evaporating feed and generating vapor, the evaporation surface (82) being located in the evaporation zone (18), wherein the injector orifice and the evaporation surface (82) are positioned to prevent the formation of a drop at the orifice (66), a treatment zone (26) for treating the vapor and at least one heater (20) associated with at least a portion of the process vessel.

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"PROCESS FOR EVAPORATION AND PROCESS VESSEL WITH INTEGRAL EVAPORATOR"

BACKGROUND OF THE INVENTION

[0001] The present invention relates processes for evaporating and treating feeds and to one or more process vessels each process vessel containing both a treatment zone and an evaporation zone; the evaporation zone for vaporizing a liquid feed within the process vessel. The present invention also relates to a single, sequential, or parallel process of vaporizing a liquid feed within the process vessel(s).

[0002] The process vessel of this invention is particularly suited for evaluating materials suitable for catalyzing reactions. Combinatorial chemistry deals mainly with the synthesis of new compounds. For example, US-A-5,612,002 B1 and US-A-5,766,556 B1 teach an apparatus and a method for simultaneous synthesis of multiple compounds. Akporiaye, D. E.; Dahl, I. M.; Karlsson, A.; Wendelbo, R. *Angew Chem. Int. Ed.* **1998**, *37*, 9-611 disclose a combinatorial approach to the hydrothermal synthesis of zeolites, see also WO 98/36826.

[0003] Combinatorial methods present the possibility of substantially increasing the efficiency of catalyst evaluation. Recently, efforts have been made to use combinatorial methods to increase the efficiency and decrease the time necessary for thorough catalyst testing. For example, WO 97/32208-A1 teaches placing different catalysts in a multi-cell holder with the heat absorbed or liberated in each cell being measured to determine the extent of each reaction. Thermal imaging has also been used; see Holzwarth, A.; Schmodt, H.; Maier, W. F. *Angew. Chem. Int. Ed.,* 1998, *37*, -47, and Bein, T. *Angew. Chem. Int. Ed.,* 1999, 3-3. Measuring the heat absorption or liberation and thermal imaging may provide semi-quantitative data regarding activity of the catalyst in question, but they provide no information about catalyst selectivity.

[0004] In order to determine the activity and selectivity of multiple catalysts, arrays of reactors have been designed to simultaneously examine multiple catalysts using the above mentioned analysis techniques. For example, EP 1108467 A2 teaches reactors with removable sections to allow easy introduction of catalyst to the reactor bed. The reactors are sealed using o-rings to allow quick connection of the reactor parts and also provide a reliable seal between the reactor parts and between each reactor and its environment.

[0010] Many process technologies and chemistries require higher-pressure gas-phase catalysis, in which a liquid feedstock is vaporized before contacting the catalyst. Many seals used for combinatorial arrays have a temperature limitation that is below the bubble point of many reactor inlet compositional mixtures. For example, the long-term temperature limitation on a typical O-ring seal is 170°C, while the bubble point of C_6 to C_9 hydrocarbons, for example toluene, at operating pressures of 2172 kPa (300 psig) to 3220 kPa (450 psig) are between 180°C and 240°C at a hydrogen to toluene molar ratio between 1 and 3.

[0011] US-A-5,453,526 B1 teaches a catalytic reactor where liquid media can be continuously introduced, evaporated, and fed to a catalytic reaction. US-A-3,359,074 teaches a polycondensation system of a single vertically extending column which is transversely partitioned to define, in descending order, a reaction chamber, an evaporator chamber, and a finishing chamber. Two articles, Bej K. S.; Rao, M. S. Ind. Eng. Chem. Res., 1991 30 (8), 1819-1832, and Eliezer K. F.; Bhinde, M.; Houalla, M.; Broderick, D.; Gates, B. C.; Katzer, J.R.; Olson, J. H. Ind. Eng. Chem. Fundam., 1977, 16 (3), 380-385 show where additional particles are used to aid in flow distribution before a feed is contacted with a catalyst. What is needed is an evaporator that can be integrated into a process vessel, that accommodates a liquid feed so that the seals will not be compromised during operation of the process vessel, while providing for the feed to be in a vapor phase during reaction.

[0012] However, evaporators in general have some inherent problems associated with their operation. One problem associated with evaporators in general is non-uniform mixing of a liquid feed and a gas feed. Non-uniform mixing may occur when both a gas and a liquid are introduced to an evaporator through a common inlet. The dual feed of liquid and gas causes alternating regions of gas entrainment and liquid pulsation being introduced to an evaporator, and therefore regions of low concentration of the vaporized species followed by regions of high concentration of the vaporized species being sent to a reactor bed.

[0013] Another problem associated with non-uniform vaporization occurs mainly because of a non-uniform flow of liquid into an evaporator. In the case of slower moving flow, a liquid issuing from an orifice into an evaporator can form droplets that detach at a regular periodicity because of the fluid dynamics of the liquid. The periodic

formation and detachment of droplets leads to non-uniform vaporization within the evaporator.

[0014] What is needed is an evaporator for use in a process vessel that overcomes the problems of non-uniform mixing and non-uniform vaporization associated with evaporators in general.

BRIEF SUMMARY OF THE INVENTION

[0015] It is an object of the present invention to provide a process vessel for vaporizing a liquid feed and treating the resulting vapor in the process vessel. It is further an object of the present invention to provide a process of vaporizing a liquid feed and treating the vapor within the process vessel.

[0016] In accordance with the present invention, a process vessel is provided for vaporizing a liquid feed within an evaporation zone before processing the feed in a treatment zone of the process vessel. The process vessel includes an evaporation zone, an orifice for injecting the liquid feed into the evaporation zone, at least one evaporation surface, a treatment zone, and a heater associated with a portion of the process vessel. The evaporation surface and the injector orifice are positioned so that the evaporation surface interferes with the formation of a droplet of liquid feed at the orifice and a thin liquid film of the liquid feed is created on the evaporation surface. The heater heats the liquid feed within the evaporation zone to a temperature sufficient to vaporize the liquid feed. It is preferred that the evaporation surface be a bed of packing.

[0017] Further in accordance with the present invention, a process is provided for vaporizing a liquid feed within the process vessel. The inventive process includes the steps of providing at least one evaporation surface in an evaporation zone of the process vessel, injecting a liquid feed into the evaporation zone through an injector orifice, and heating and vaporizing the liquid feed within the evaporation zone of the pr ocess vessel. A gap formed between the injector orifice and the evaporation surface is sufficiently small so that the evaporation surface interferes with the formation of a liquid feed droplet at the orifice. The liquid feed is instead directed to form a thin liquid film on the evaporation surface which facilitates uniform vaporization and uniform concentration in the resulting vapor. The vaporized feed is flowed to a treatment zone of the process

vessel and treated within the treatment zone to generate an effluent. It is preferred that the evaporation surface be a bed of packing.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

FIG. 1 is an exploded side view of a reactor.

FIG. 2 is a top view of an insert.

FIG. 3 is a cross-sectional side view of an assembled reactor.

FIG. 4 is a side close up view of the orifice of the injector and the packing.

FIG. 5 is a side view of an alternative assembled reactor.

FIG. 6 is a side view of an assembled array.

FIG. 7 is a perspective view of the array and the quick connect system.

DETAILED DESCRIPTION OF THE INVENTION

[0018] The invention is explained in terms of the preferred embodiment where the process vessel is a reactor having an evaporation zone and a reaction zone. Other vessels are within the generally broad scope of the invention. Furthermore, other treatment zones in addition to a reaction zone are within the generally broad scope of the invention. Referring to the figures, there is shown a reactor 10 for evaporating liquid feed and reacting the feed in the presence of catalyst 24 to make a product. In the inventive reactor, seals 28 and 30 maintain a reliable seal between reactor 10 and the environment while vaporizing liquid feed within reactor 10. Reactor 10 is particularly useful for evaluation of catalyst 24 for a specific reaction. Reactor 10 may also be used in an array 120 for the simultaneous reaction of a liquid feed over several catalysts and for their evaluation in a combinatorial method. The integrated vaporization of the liquid feed makes reactor 10 more versatile than previous reactors by allowing the introduction of liquid components into reactor 10 with subsequent vaporization before contact with catalyst 24.

A. Reactor

[0019] Turning to FIG. 1, reactor 10 includes a housing 12 for housing reactor 10, a header 14 providing feed inlets for housing 12, an insert 16 attached to header 14 which retains an evaporation zone 18 for vaporizing the liquid feed, an evaporator heater 20

(see FIG. 3) for providing the heat to vaporize the liquid feed and form a vapor, and a receptacle 22 that retains a catalyst 24. Catalyst 24 forms part of a treatment zone as a reaction zone 26. The vapor contacts catalyst 24 and reacts to form a product. A gas feed may also enter reactor 10, mix with the vapor in the evaporation zone 18, and react with the vapor in the presence of catalyst 24 to form the product gas.

[0020] The liquid feed may be any liquid component or mixture of liquid components capable of vaporization under predetermined temperatures and pressures and intended to undergo a reaction capable of catalyzation by catalyst 24. The feed is preferred to be a liquid hydrocarbon mixture. Suitable hydrocarbon mixtures include aromatic, aliphatic, and naphthene compounds having six or more carbon atoms, preferably six to nine carbon atoms. The liquid feedstock may also contain or comprise one or more components having hydrogen, carbon, and another element such as oxygen, chlorine, sulfur, nitrogen, and the like.

[0021] Reactor 10 may include a gas feed as well as a liquid feed. The gas feed may be any an organic or inorganic gas. Preferably the gas feed undergoes a catalyzed reaction by catalyst 24, provides a stabilizing effect on the catalyst, or activates or reactivates reactive sites on the catalyst. It is preferred that the chemical composition and flow rate of the gas feed into reactor 10 feed be known so that calculations can be performed to determine an activity and selectivity for catalyst 24 as described below. Examples of gas feeds are hydrogen, oxygen or light gas phase hydrocarbons such as methane or ethane. Alternatively an inert gas, such as Nitrogen, can act as a carrier for the vaporized liquid feed. The feed to the reactor of the present invention may be one or more liquid phase feeds, or a combination of one or more gas phase feeds and one or more liquid phase feeds.

[0022] Both the liquid feed and the gas feed are usually introduced to reactor 10 in measured amounts and with known chemical compositions. The known amount of each component entering reactor 10 combined with the measured flow rate and the analyzed composition of the product gas is used to determine the activity, feed conversion, major product and byproduct selectivities and yields of catalyst 24 in reactor 10.

[0023] A first seal 28, placed between the header 14 and the housing 12, provides a barrier between reactor 10 and its environment and a second seal 30, placed between the insert 16 and receptacle 22, prevents leaks between the insert 16 and receptacle 22. The

removable parts of reactor 10, along with seals 28 and 30, allow for easy assembly and disassembly of reactor 10, as well as allowing individual parts to be replaced if needed. The ability of housing 12, insert 16 and receptacle 22 to be removed and replaced allows easy assembly of reactor 10, which is beneficial for the experimental setup of a combinatorial array 120.

[0024] Housing 12, shoulder 36 and related components are described in their preferable cylindrical size and shape, but other shapes and sizes of reactor 10 could also be successfully employed. Reactor 10 could be scaled up to a pilot plant or even a commercial scale or scaled down to micro-scale without varying from the generally broad scope of the invention. Thus reactor 10 of the present invention is not limited to the dimensions described herein and which suit its preferred use in a combinatorial-scale reactor.

[0025] Housing 12, header 14, insert 16, receptacle 22 and other related components are preferably constructed out of a material that is inert to reaction with the liquid and gas feeds, is resistant to corrosion, can withstand temperatures of from 10°C to 1000°C, and has good heat transfer properties. Preferably the corresponding components are all constructed from the same material. Examples of suitable materials of construction include metals and their alloys, low grade steel, stainless steels, super-alloys like Incolloy, Inconel and Hastelloy, engineering plastics and high temperature plastics, ceramics such as silicon carbide and silicon nitride, glass, and quartz. A preferred material of construction is 321 stainless steel.

1. Housing

[0026] As shown in FIG. 1, housing 12 includes an inlet end 32 for receiving feeds and an outlet end 34 for products. Housing 12 encases evaporation zone 18 and reaction zone 26. Housing 12 includes a shoulder 36 at inlet end 32 of housing 12, a main section 38 between shoulder 36 and outlet end 34, and a product conduit 40 at the outlet end 34. Product conduit 40 is attached to housing 12 at the outlet end 34 and allows a path for product withdrawal from reactor 10. Surface 42 of shoulder 36 engages seal 28 between housing 12 and header 14. Seal 28 blocks feed leakage from reactor 10 into the environment. Shoulder 36 or header 14 may retain seal 28. A preferred material of construction of shoulder 36 is 316 stainless steel.

[0027] Seal 28 may be any type capable of forming a reliable, pressure-tight seal between housing 12 and header 14, but is preferably of a type that allows quick assembly of reactor 10. An acceptable seal 28 is an elastomeric O-ring, or set of O-rings engaged between housing 12 and header 14. However, typical elastomeric O-ring seals have a maximum temperature limitation for long-term operation of between 170°C and 300°C. The bubble points of most liquid feeds will exceed these limits. For example, boiling points of C_6 to C_9 hydrocarbons at pressures of between 2860 kPa (400 psig) and 3351 kPa (500 psig) range from 300°C and 400°C. The present invention overcomes these limitations and may operate in a vacuum or at pressures higher than 3351 kPa (500 psig). Only the differential pressure limitation of seal 28 restricts the reactor operating pressure.

[0028] Bubble or boiling points that exceed the maximum seal temperature limitations prohibit vaporization of such liquid feeds upstream of reactor 10. In such cases placing evaporator 44 within reactor 10 and downstream of seal 28 avoids this problem by keeping the temperature of seal 28 below its maximum. Desirable seals 28 and 30 will reside in a cool zone that is separate from the heated evaporation zone 18.

[0029] In a preferred combinatorial arrangement main section 38 of housing 12 may have a length of between 13 cm and 14 cm and an inner diameter of between 0.4 cm and 0.5 cm. Shoulder 36 may have a length of 1.0 cm and a diameter of between 0.8 cm and 1.0 cm. Product conduit 40 may have an inner diameter of less than 1 mm to 1.5 mm.

[0030] Header

[0031] As shown in FIG. 1, header 14 and insert 16 connect to form a single piece by any number of methods such as threading, bolting or welding. Preferred methods allow their disengagement from one another for change out of packing 76, if desired.

[0032] Header 14 provides fluid to inlet end 32 of housing 12. Header 14 also provides a surface 46 for seal 28 to engage between header 14 and housing 12 at shoulder 36, however seal 28 could engage between housing 12 and insert 16. Header 14 includes an injector 48 for a liquid feed inlet, a gas feed inlet 50, a diluent gas inlet 52 and a guide tube 56 for a thermocouple 54 to measure the temperature within reactor 10. Header 14 is received by housing 12 at inlet end 32.

[0033] It is preferred that the cross-section of header 14 be of the same general shape as the cross-section of housing 12 so that header 14 will easily fit within shoulder 36 of

housing 12 within predetermined tolerances. The generally cylindrical shape illustrated for header 14 corresponds to the preferred shape of housing 12.

[0034] The length of header 14 preferably exceeds the length of shoulder 36 and the diameter of header 14 is preferably slightly smaller than the diameter of shoulder 36 within tolerance limits so that an adequate seal can be formed between header 14 and housing 12. Preferably the diameter of header 14 is large enough to accommodate injector 48, gas feed inlet 50, diluent gas inlet 52 and guide tube 56. In one embodiment, header 14 may have a length between 1.0 cm and 1.5 cm and a diameter of between 0.8 cm and 0.9 cm.

[0035] In the preferred form header 14 will retain an injector 48 in a position for its penetration through inlet end 32 and substantially into the interior of insert 16 to establish fluid communication and introduce liquid feed through an orifice 66 located at the end of injector 48. Preferably, orifice 66 is located within evaporation zone 18 to introduce liquid feed directly into evaporation zone 18. Preferably, injector 48 is approximately centered radially across the annulus of insert 16. The radial centering allows for uniform distribution of the liquid feed within evaporator 44. Injector 48 is preferably tubular with a small inside diameter that defines orifice 66. In one embodiment the diameter of orifice 66 may be 0.2 mm and injector 48 may extend 5 cm within insert 16.

[0036] Gas feed inlet 50 extends through header 14 and is in fluid communication with insert 16 so that a gas feed introduced to the insert 16 and preferably enters upstream of a liquid feed introduced to insert 16. The diameters of gas feed inlet 50 may exceed the diameter of the liquid feed inlet. The diameter of gas feed conduit is chosen to accommodate a predetermined flow rate of gas feed. In one embodiment gas feed inlet 50 may have a diameter of less than 1 mm.

[0037] Diluent gas inlet 52 extends through header 14 and through a fluid path 68 in reactor 10 so that the diluent gas can bypass catalyst 24 and dilute the product stream and prevent condensation or plating. The diameter of diluent gas inlet 52 accommodates a predetermined flow rate of the diluent gas. Typically, diluent gas inlet 52 may have a diameter less than 1 mm.

[0038] Optional thermocouple 54 extends into reactor 10 for measuring the temperature within housing 12 and, preferably, within reaction zone 26. A guide tube 56

in header 14 may extend the length of insert 16 to retain thermocouple 54 and pass it into a receptacle 22 to generally center a sensor 70 of thermocouple 54 within reaction zone 26. However, only the location of sensor 70 affects the invention. Thermocouple 54 may be placed so that it is inserted through the sides of housing 12 and receptacle 22 so that sensor 70 is generally centered within reaction zone 26.

[0039] Optional guide tube 56 provides easy placement of thermocouple 54 in reactor 10 and into reaction zone 26. The diameter of tube 56 depends on the diameter of thermocouple 54 and tube 56 may have an inner diameter of less than 1 mm.

3. Insert

[0040] Header 14 is adjacent to insert 16 so that injector 48 and gas feed inlet 50 are in fluid communication with evaporation zone 18. Header 14 and insert 16 are placed within housing 12 so that engagement of seal 28 between header 14 and housing 12 seals reactor 10 from its environment and positions insert 16 within receptacle 22. Insert 16 is preferably removable. Insert 16 includes an inlet end 72 and an outlet end 74. Insert 16 preferably contains packing 76 to form a bed 78 within evaporation zone 18 for vaporizing the liquid feed to form a vapor.

[0041] A fluid permeable member 80 attached at outlet end 74 of insert 16 retains packing 76, but still allow fluids, such as the gas feed and the vapor to pass into receptacle 22 for contact with catalyst 24. Fluid permeable member 80 is preferably a sintered metal, such as Hastelloy, but could be any material permeable to the fluids flowing into reaction zone 26 and sufficiently strong to support packing 76. Other materials for member 80 include glass, sintered glass, Raney metals, electro-bonded membranes, etched alloy membranes, and fine meshed screens with gaps smaller than the minimum packing size, but large enough for adequate flow of gas feed and vapor.

[0042] Packing 76 could be in any form, so long as it interferes with the formation of a droplet and provides surfaces 82 for the liquid feed to form a thin liquid film 84. Packing 76 may be particulate packing, as shown in FIG. 4, or it may be a prefabricated, structured monolithic packing, or it may be another means to interfere with droplet formation and provide surfaces for the formation of a thin liquid film 84, such as a metal insert placed within evaporation zone 18 near orifice 66.

[0043] Thin liquid film 84 allows efficient evaporation of the liquid feed when heat is provided by an evaporator heater 20. Preferred particulate packing 76 is preferably inert to the gas feed and the liquid feed and may be any inert packing material, such as alumina, and preferably microporous alumina. Packing 76 may be of a uniform size with the same diameter for each particle, or of a random size with minimum and maximum particle diameters. When the injector 48 extends into insert 16 the minimum diameter of packing 76 preferably exceeds the diameter of orifice 66 so that packing 76 does not clog injector 48, and the maximum diameter of packing 76 should not exceed 10% of the inner diameter of insert 16 to prevent the formation of wall flow along its interior surface. In one embodiment, the diameter of packing 76 may be between 0.21 mm and 0.42mm.

[0044] In one embodiment, insert 16 may have a length of 10 cm and a diameter of 0.3 cm. The diameter of insert 16 allows it will fit within receptacle 22 within predetermined tolerances.

[0045] Insert 16 also provides a surface 86 for seal 30 to engage between insert 16 and receptacle 22. Seal 30 prevents the feeds from leaking past catalyst 24 and prevents the diluent gas from passing into receptacle 22 and coming into contact with catalyst 24. Insert 16, header 14 or receptacle 22 may retain seal 30. Seal 30 may comprise the same materials as those described for seal 28.

4. Evaporator – Evaporation Zone

[0046] Because of bubble points higher than the limitations of most seals, the arrangement of reactor 10 preferably places the evaporator 44 downstream of seals 28 and 30 so that the maximum temperature limitation is not reached at these seals. Effectively integrating an evaporator within reactor 10 requires overcoming some inherent problems to provide a vaporized gas stream with a constant and uniform composition. One of these problems is non-uniform mixing of a gas feed and liquid feed, and another is non-uniform vaporization of a liquid feed. If the composition of the gas entering reaction zone 26 is not uniform, it will create unreliable data for the evaluation of catalysts.

[0047] In general problems of non-uniform mixing liquid feed and gas feeds plague evaporators. Introducing both a gas and a liquid to an evaporator through a common inlet promotes non-uniform mixing. The combined feed of liquid and gas causes alternating

regions of gas entrainment and liquid pulsation in the evaporator, and therefore regions of low concentration of the vaporized species followed by regions of high concentration of the vaporized species pass to a reactor bed.

[0048] Another general problem is non-uniform vaporization caused mainly by non-uniform flow of liquid into an evaporator. In the case of slower moving flow, liquid issuing from an orifice into an evaporator can form droplets that detach at a regular periodicity because of the fluid dynamics of the liquid. The periodic formation and detachment of droplets leads to non-uniform vaporization within the evaporator.

[0049] A stream of liquid issuing out of an orifice can become unstable due to capillarity. This instability results in the formation of droplets the size of which can be accurately predicted by linear stability analysis. The character of the liquid breakup at the orifice is primarily controlled by the Weber number, We:

$$We = \frac{\rho D U^2}{\sigma}$$

where D is the diameter of the orifice, U is the average liquid velocity, ρ is the liquid density and σ is the surface tension. The Weber number expresses the balance between external kinetic force and surface force, wherein the external force on the droplet is defined by:

$$F_D = \frac{\rho U^2}{2} \cdot \frac{\pi D^2}{4}$$

and the surface force of the droplet is defined by:

$$F_S = \pi D \sigma$$

The free interface of the droplet is stable when $F_D < F_S$ or:

$$\frac{\rho U^2}{2} \cdot \frac{\pi D^2}{4} < \pi D \sigma \qquad We = \frac{\rho D U^2}{\sigma} < 8$$

[0050] When the Weber number is less than 8, a stable interface is created and uniform axi-symetric droplets form at the orifice. In the case of reactor 10, liquid is introduced to evaporator 44 at low liquid flow rates, which result in low liquid velocities. For reactor 10, it is not uncommon to have Weber numbers that are much less than one.

At very low Weber numbers the droplets approach static equilibrium conditions, and the droplet diameter can be very accurately predicted using the Young-LaPlace equation:

$$\left(\frac{\pi s^3}{6}\right) g(\rho_L - \rho_G) = \pi\ D\ \sigma$$

where s is the predicted diameter of the droplet, g is the acceleration of gravity, ρ_L is the density of the liquid, ρ_G is the density of the gas, D is the diameter of the orifice and σ is the surface tension of the liquid.

[0051] The droplet volume and liquid flow rate allow the estimation of droplet detachment times, in the case of reactor 10 of between 4 and 6 seconds. The periodic detachment of droplets leads to severe malfunctioning patterns of vapor concentrations associated with non-uniform vaporization of the droplets.

[0052] In the preferred evaporator 44 of the present invention, the problem of non-uniform mixing is solved by feeding the liquid feed and gas feed at different locations within insert 16 so that mixing occurs between the gas feed and liquid feed in evaporation zone 18, not in injector 48. Liquid feed enters insert 16 through orifice 66 of injector 48, where orifice 66 is a substantial distance down the length of insert 16, while gas feed enters insert 16 near inlet end 72 of insert 16. Preferably, orifice 66 is located within evaporation zone 18.

[0053] To prevent droplet formation and detachment and the resulting non-uniform vaporization, at least one evaporation surface, such as surfaces 82 of packing 76, is placed at the entry point of the feed, and preferably within the evaporator 44 relative to orifice 66 of injector 48, to interfere with the formation of droplets.

[0054] Evaporation surfaces other than those on packing 76 as described may be successfully employed in the present invention. Examples of such evaporation surfaces include, but are not limited to, plates, a porous monolith, a cone, and the like. The selected evaporation surface is positioned to prevent the formation of a droplet at orifice 66 of injector 48. The description herein will exemplify the preferred embodiment where the evaporation surfaces are surfaces 82 of packing 76, however, the invention may employ other suitable evaporation surfaces.

[0055] Bed 78 provides a preferred evaporation zone 18 necessary to effectively vaporize the liquid feed. Evaporation zone 18 is encased within housing 12. FIG. 4

shows injector 48 and packing 76 at the point where the liquid feed is injected into bed 78. Injector 48 includes orifice 66 with a diameter D at its terminal end. Liquid feed flows through injector 48 at a average liquid flow rate, U, that would result in the periodic formation of a droplet 88 with a diameter, s, as shown in FIG. 4, where s is determined by the Young-LaPlace equation. Packing 76 is placed in close proximity to orifice 66, defining a gap 90 between orifice 66 and packing 76. If gap 90 is sufficiently smaller than the predicted diameter s of droplet 88, then packing 76 will interfere with the formation of a stable interface and droplet 88 fails to form. Instead, the liquid feed forms a thin liquid film 84 on the surfaces 84 of packing 76 allowing uniform vaporization of the liquid feed. Because of the uniform vaporization, a constant concentration of vapor is contacted by catalyst 24, resulting in accurate results obtained by reactor 10. Preferably gap 90 is minimized to be as small as possible without plugging orifice 66 to ensure that packing 76 interferes with the creation of a stable interface of droplet 88.

[0056] Unexpectedly, a minimized gap 90 between packing 76 and orifice 66 in evaporator 44 proved so effective that attempts to reproduce non-uniform vaporization by setting evaporator heater 20 low enough so that the temperature of the liquid feed is below its bubble point until well into bed 78 were unsuccessful. No malfunctioning concentration patterns were created by evaporator 44 despite attempts to artificially produce them.

[0057] In order to ensure adequate flow distribution over packing 76 in bed 78, it is important to use appropriate sizes of packing 76. As previously mentioned diameters of packing 76 should be small enough to avoid a "wall effect" of the liquid flowing along the inner surface of insert 16 and large enough to prevent clogging of orifice 66 by particles of packing 76.

[0058] Evaporator 44 of reactor 10 is not limited to use in a reactor. The inventive evaporator 44 of the present invention could also be used in another process vessel where it is desirable to vaporize a liquid feed, followed by further processing in a treatment zone within the same process vessel. The process vessel would have both an evaporation zone and a treatment zone, with the evaporation zone including the evaporator 44. In the case of the present invention, reactor 10 is the process vessel and reaction zone 26 is the treatment zone of the vapor.

5. Evaporator Heater

[0059] Evaporator heater 20 provides the necessary energy to vaporize liquid feed within bed 78. Evaporator heater 20 is associated with a portion of reactor 10. Preferably, evaporator heater 20 is associated primarily with evaporation zone 18 at the point where the liquid feed is injected into bed 78 as shown in FIG. 3, although other locations may work. The duty of evaporator heater 20 is preferably provided by electrical resistive heating against or adjacent to housing 12. Evaporator heater 20 could be a heater block with a thickness larger then the diameter of housing 12 so that evaporator heater 20 is placed around housing 12 housing 12. However, evaporator heater 20 could be any other type of heater, such as one utilizing a heat transfer fluid. In one embodiment, the thickness of evaporator heater 20 may be 8 mm.

[0060] Evaporator heater 20 is set at a temperature sufficient to vaporize the liquid feed within evaporation zone 18, forming a vapor. Preferably, the temperature of the liquid feed at orifice 66 is below its bubble point, and evaporator heater 20 is set so that the liquid feed is heated to above its bubble point within evaporation zone 18, creating a temperature gradient within evaporation zone 18. Still more preferably, evaporator heater 20 is set so that a temperature gradient is created throughout evaporation zone 18 so that the temperature of the vapor is heated to a predetermined reaction temperature within evaporation zone 18 before the vapor enters reaction zone 26.

6. Receptacle

[0061] Referring to FIG. 3, receptacle 22 is placed within housing 12, and insert 16 is placed within receptacle 22 in a nested configuration so that seal 28 engages header 14 and shoulder 36 of housing 12 and seal 30 engages insert 16 and receptacle 22. Receptacle 22 is preferably removable. Receptacle 22 includes an inlet end 94 and an outlet end 96. A flange 98 is attached to inlet end 94. Flange 98 of receptacle 22 includes cut-out sections 102 (See FIG. 2) to allow a diluent gas to pass through. The diluent gas passes through cut-out sections 102 in flange 98 and into a fluid path 68 formed between receptacle 22 and main section 38 of housing 12. Preferably the diameter of flange 98 is the same as the diameter of shoulder 36

[0062] Receptacle 22 retains catalyst 24, within reaction zone 26 where the feed and the vapor contacted catalyst 24 at reaction conditions to form a product. A fluid permeable member 104 is attached at outlet end of receptacle 22 to retain catalyst 24, but

allow fluids, such as unreacted feeds and product gas, to pass out of receptacle 22 and exit reactor 10 out of product conduit 40. Fluid permeable member 104 is preferably a sintered metal, such as Hastelloy, but could but could be any of the material such as those recited for permeable member 80 that is permeable to the fluids passing out of receptacle 22 and sufficiently strong to support catalyst 24.

[0063] Catalyst 24 is selected to provide active sites for the desired reaction. Catalyst 24 may be any material or mixture of materials that possibly catalyze the desired reaction, but preferably catalyst 24 is a zeolite or some other type of catalyst that can be synthesized by combinatorial methods. In one embodiment, an effective mass of catalyst 24 placed within receptacle 22 of reactor 10 may range from 1 mg to 1 gram, but the amount of catalyst 24 is not limited to the above masses.

[0064] Reaction zone 26 is flanked by fluid permeable members 80 and 104 upstream and downstream of catalyst 24 and by inner surface 106 of receptacle 22 on the side so that catalyst 24 remains within reaction zone 26. In one embodiment, reaction zone 26 may have a height of between 1.0 cm and 1.5 cm. The length of receptacle 22 is approximately the same as the length of main section 38 of housing 12. The lengths of insert 16 and receptacle 22 are chosen so that reaction zone 26 has its desired height. The diameter of receptacle 22 is chosen to provide fluid path 68 between receptacle 22 and housing 12 and allow the diluent gas to bypass reaction zone 26 as shown in FIG. 3. Alternately channels or groves in receptacle 22 or housing 12 may allow the diluent gas to bypass reaction zone 26. In one embodiment, receptacle 22 may have a length of between 10 cm and 14 cm and a diameter of between 0.4 cm and 0.5 cm.

7. Reaction Heater

[0065] Preferably a reaction heater 108 is placed adjacent to housing 12 so that it is associated primarily with reaction zone 26 and so that it surrounds all of reaction zone 26. Reaction heater 108 provides heat for reaction zone 26 to maintain catalyst 24 and reaction zone 26 at a controlled constant temperature. Reaction heater 108 can be any type of heater to provide the heat needed for reaction zone 26, such as an aluminum-bronze oven using electrical resistive heating.

[0066] FIG. 3 shows reaction heater 108 placed around outlet end of housing 12 so that all of reaction zone 26 is within the oven. In one embodiment, reaction heater 108

may have a thickness of 9 cm and it may surround 4 cm and 6 cm of reactor 10. However, reaction heater 108 is not limited to the above dimensions.

[0067] Preferably, the length of reactor 10 between evaporator heater 20 and reaction heater 108 keeps the temperature at packing 76 substantially independent of the temperature at catalyst 24. The setting of heater 108 will preferably not substantially affect temperature of the liquid feed at orifice 66 of injector 48 and the evaporator heater 20 should not affect the temperature within reaction zone 26. In one embodiment, the length of reactor 10 between evaporator heater 20 and reaction heater 108 may be between 2.5 cm and 8 cm.

8. Diluent Gas and Diluent Zone

[0068] Some reaction mixtures of reactor 10 include a liquid feed or a product that has a high dew point. This creates a problem for a product mixture exiting reactor 10 through outlet end after leaving reaction heater 108 because the temperature of the reaction mixture decreases to below the mixture's dew point, causing liquid feed or product to condense out of the gas phase. Some products also have a high freezing point so that in addition to condensing the material can form a solid and plate along product conduit 40. Condensing or plating of product can block or obstruct flow through product conduit 40, and/or alter the gas phase composition of the product stream. Because it is the gas phase composition that is measured by analyzing downstream of reactor 10, condensation or plating can adversely impact experimental results determined by reactor 10.

[0100] The addition of a diluent gas to reactor 10 allows for a reduction in pressure for analysis of product, while preventing the condensation and plating of product. As shown in FIG. 3, diluent gas enters through diluent gas inlet 52 of header 14 and passes through cut-out sections 102 in flange 98 of receptacle 22 where it flows into fluid path 68 between receptacle 22 and main section 38 of housing 12 thereby bypassing catalyst 24. Fluid path 68 communicates diluent gas inlet 52 with diluent gas mixing zone 110. A difference in diameter between housing 12 and receptacle 22 as diluent path 68, as shown in FIG. 3, or housing 12 and receptacle 22 may have a small tolerance between them andgrooves or channels in either housing 12 or receptacle 22 may form diluent path 68. Grooves or channels (not shown) may provide more efficient heat transfer between the diluent gas and evaporation zone 18 and reaction zone 26. Desirably the inlets for the

liquid feed, the gas feed and the diluent gas all introduce fluid into the apparatus at the same general location. However, diluent gas can enter mixing zone 110 by any method, such as a separate conduit that communicates with mixing zone 110.

[0069] The diluent gas dilutes product and unreacted feeds in mixing zone 110 downstream of reaction zone 26 thereby lowering the concentration and partial pressure of trace undesirable by-products in the reactor effluent to prevent condensation, plating and/or subsequent equipment fouling. The diluent gas may mix with the product stream at any point downstream of reaction zone 26, but preferably it mixes before product conduit 40 exits reaction heater 108.

[0070] The diluent gas may be any gas capable of mixing with the product stream and that dilutes the product and suppresses the partial pressure to prevent condensation or plating of the product or unreacted feed. Preferably feed gas serves as diluent to permit supply from a common reservoir. Like the liquid feed and the gas feed, diluent gas is introduced to reactor 10 in a measured amount and with a known composition so that the amount of each component being mixed with the product gas is known.

9. Sampling and Analyzing

[0071] When reactor 10 is used to evaluate catalysts by determining their activity and/or selectivity at least a portion of the product gases flowing through product conduit 40 is analyzed by an analyzer 112 to determine its chemical composition. In one embodiment, a portion of the product is sampled prior to analyzation by analyzer 112. Therefore the analyzer can be located at reference number 112, or a port to conduct a portion of the product to an analyzer at another location can be located at reference number 112. The flow rate of product in product conduit 40 is typically also measured. Analyzer 112 can use any method to determine each product gasses composition, but preferably uses one of the following analytic techniques; spectroscopy, spectrometry, chromatography, nuclear magnetic resonance, or a combination thereof.

10. Alternative Embodiment with Cooler

[0072] Seals 28 and 30 both typically have a maximum temperature limitation below the bubble point of many liquid feeds that enter reactor 10. In an alternative embodiment of reactor 10, shown in FIG. 5, a cooler 114 maintain seals 28 and 30 at or below their maximum temperature limit. Cooler 114 is preferably adjacent to both seals 28 and 30

and Fig. 5 shows its placement adjacent to housing 12 between evaporator heater 20 and header 14.

[0073] Cooler 114 may be of any type capable of removing the necessary heat to maintain desired seal temperatures and is preferably a plate heat exchanger cooled with water flowing through a conduit within plate 116. Plate 116 can comprise any heat conducting material, but aluminum is preferred. In one embodiment the thickness of plate 116 of cooler 114 is 1 cm and the diameter of a cooling water conduit (not shown) within plate 116 is 0.1588 cm.

B. Process of Evaporating and Reacting in a Reactor

[0074] One process by which reactor 10 vaporizes a liquid feed and reacts the resulting vapor in the presence of catalyst 24 includes the steps of providing packing 76 in evaporation zone 18, providing catalyst 24 in reaction zone 26, introducing a liquid feed to evaporation zone 18, heating and vaporizing the liquid feed within evaporation zone 18 to form a vapor, flowing the vapor into reaction zone 26, and contacting the vapor with catalyst 24 at predetermined reaction conditions to form a product. In some cases a gas feed may also be introduced to reactor 10 so that both the gas feed and the vapor are contacted with catalyst 24 in reaction zone 26 to react and form a product.

[0075] In one process, catalyst receptacle 22 is placed containing catalyst 24 for reacting vaporized feed within housing 12 where receptacle 22 is positioned within reactor 10 so that catalyst 24 is within reaction zone 26, insert 16 is placed containing packing 76 having surfaces 82 for evaporating feed where insert 16 is positioned within receptacle 22 so that packing 76 is within evaporation zone 18, the liquid feed is injected into evaporation zone 18 through injector 48 in a measured amount, where it passes through header 14 and into insert 16. Next, liquid feed is injected through orifice 66 in injector 48 into bed 78 formed by packing 76, and forms a thin liquid film 84 on the surfaces 82 of packing 76. Evaporator heater 20 heats the liquid feed at or near orifice 66 to form a vapor within evaporation zone 18. Packing 76 provides the gap 90 defined between orifice 66 and packing 76 to interfere with droplet formation. Feed originally liquid and now vaporized within bed 78 passes through fluid permeable member 80 and into reaction zone 26. Any gas feed entering reactor 10 preferably enters through header 14 via insert 16 in a measured amount at some point upstream of orifice 66. The gas

feed mixes with the vapor in evaporation zone 18 and acts as a carrier gas for the vapor as it takes the same path into reaction zone 26.

[0076] Reaction heater 108 quickly heats the vaporized hydrocarbon feed any gas feed, and catalyst 24 to a predetermined reaction temperature in reaction zone 26. Thermocouple 54 may constantly measured the temperature of reaction zone 26 to control the setting of reaction heater 108. Contacting the vapor and any gas feed with catalyst 24 initiates at least one reaction to generate a product mixture of a product, byproducts, and unreacted feeds. The product mixture then flows out of reaction zone 26 through fluid permeable member 104 and into product conduit 40, where it is carried away from reactor 10. Fig 6 shows analyzer 112 for sampling and analyzing at least a portion of the product mixture to determine its chemical composition preferably by spectroscopy, chromatography, nuclear magnetic resonance, and combinations thereof.

[0098] In an alternate embodiment, reaction heater 108 may also heat the packing 76 in evaporation zone 18. Heating the packing with reaction heater 108 may establish a gradient across packing 76. Adjusting the positioning of reaction heater 108 with respect to the distance between reaction zone 26 and packing 76 may control heating of packing 76.

[0101] If it is desired, a diluent gas dilutes the product mixture in mixing zone 110 after it passes through fluid permeable member 104 so that the diluent gas preferably avoids contact with catalyst 24. The diluent gas quickly mixes with the product mixture in mixing zone 110 of product conduit 40 to form a diluted product mixture. At least a portion of the diluted product mixture may then enter analyzer 112.

C. Array of Multiple Reactors

[0102] Use of reactor 10 in an array 120 of two or more parallel operating reactors 10 provides its fullest range of utility. Parallel operation of an array 120 allows testing of the same catalyst at several different reaction conditions, testing of a plurality of different catalysts, testing of a plurality of feeds with catalysts, or a combination thereof. Calculating activity and selectivity of each catalyst 24 at for various conditions can indicate the most effective catalyst and the optimal conditions for the reaction of interest.

[0103] FIG. 6 shows an array 120 of two or more reactors 10. Each of the reactors 10 of array 120 have all of the elements described above for reactor 10. Reactors 10 in

array 120 can operate at different reaction conditions. Although the array may employ multiple independent heaters, Fig 6 shows one evaporator heater 20 associated with each of the outside surfaces 92 of each of the housings 12 to heat the liquid feed at the orifices 66 of the injectors 48 for each reactor 10.

[0104] Reactors 10 in array 120 are arranged to perform the same reaction so that common liquid feed, gas feed, and diluent gas enter to each reactor 10 in array 120. The liquid feed, gas feed and diluent gas enter reactors 10 simultaneously so that reactors 10 operate in parallel allowing several catalysts 24, or several reaction conditions, to be evaluated simultaneously.

[0105] A plurality of housings 12 can be formed from a single tray or block of material. Preferably that housings 12 are free-standing units so individual housings 12 may be replaced as needed due to damage or change-out. It is also preferred that a common bottom support 122 retain housing 12 so that the plurality of housings 12 can move as a single unit for the convenience of handling an assembly of all units rather than manipulating multiple individual housings 12. Also, robotics is more readily adapted to manipulating a single tray. Although not necessary, each housing 12 and inserts 16 in array 120 is preferably constructed of the same material typically the same as those previously described.

[0106] Each housing 12 of array 120 has a corresponding insert 16 and header 14 with the features as described above. Preferably each of the headers 14 connected to a top support 126 so that a corresponding insert 16 is placed inside the housing 12 to enclose the plurality of reactors 10 in array 120. Top support 126 connects the plurality of headers 14 and inserts 16 for convenient movement as a single unit. Also connection of housings 12 to bottom support 122 and connection of headers 14 to top support 126, permits assembly of the plurality of headers 14 and inserts 16 as a single pieces, thereby allowing a one step assembly of array 120. Although not required, each header 14 and insert 16 of array 120 is preferably constructed of the type of material selected from those previously described and more preferably from the same material as the corresponding housings 12.

[0107] Top support 126 and bottom support 122 may provide for the connection of any number of individual headers 14 and housings 12. For example, top support 126 or bottom support 122 may connect to 6, 8, 12, 24, 48, 96 or 384 of headers 14 or housings

12. The number of headers 14 or housings 12 need not fill the full capacity of a particular top or bottom support. For example, a top support 126 capable of holding 48 of headers 14 may only support only 24. Likewise, the number of reactors 10 in an array 120 can be changed simply by adding or taking away a desired number of housings 12 from bottom support 122.

[0108] Top support 126 could be any shape or configuration capable of supporting the plurality of inserts 16 in a desired, predetermined pattern, but it is preferred that top support 126 be a plate with holes for each corresponding header 14. FIG. 6 and FIG. 7, show the plate of top support 126 including generally planar surface 128.

[0109] Top support126 and bottom support 122 may be constructed of any suitable material. These include the previously described materials for the housing, inserts, etc. and in addition Teflon polymer, nylon, and low temperature plastics such as polyethylene, and polypropylene. Preferably the top and bottom supports will resist twisting from torque so they remains substantially planar throughout operation of array 120. Preferred materials for the top and bottom supports will withstand temperatures of from 0°C to 1000°C.

[0110] Top support 126 and bottom support 122 could be any shape or configuration capable of supporting the plurality of housings 12 in a desired, predetermined pattern. Typically the top and bottom supports are plates with holes for either each header 14 or housing 12. FIG. 6 and FIG. 7, show the plate of bottom support 122 including a generally planar surface 124.

[0111] The top and bottom supports will usually retain headers 14 with the inserts 16 and housings 12 in a grid pattern but the supports may use any number of geometrical patterns. Preferably the top and bottom supports have dimensions similar to the dimensions of commonly used micro titer trays.

[0112] Each set of housings 12 and corresponding inserts 16 has corresponding receptacles 22 of the type previously described. Apart from its use in array 120 each reactor 10 is assembled in the same manner as described previously described and preferably constructed from the same material as the housing 12 or insert 16. or both.

[0113] To fully realize the greatest utility array 120 will include an apparatus for its quick assembly and disassembly. Seals 28 and 30 aid in this quick-connect by allowing

quick assembly of each reactor 10 while still preventing leaks between reactor parts and between reactor 10 and its environment. Seal 28, 30 seal the plurality of reactors 10 simultaneously. Quick-connect system 130 provides an apparatus and a method to raise and lower supports 122 and 126 while still assuring high precision in the horizontal plane, allowing seals 28 and 30 to seal effectively in each reactor 10. A quick-connect system can raise and lower one of the housing support 122 or insert support 126 with the other remaining stationary, or a single or multiple quick-connect systems raise and/or lower both supports 122 and 126 as desired.

[0114] FIG. 7 shows an embodiment of a quick-connect system 130 having a set of two threaded guide rods 132 with a wheel 136 at a lower end of each rod. Each rod extends through a threaded hole 140 defined by guide ring 134 and a hole 142 defined by a stationary ring 136. Guide rings 134 attach to and extend away from insert support 126. Stationary support 144 anchors stationary ring 136 against movement while guide rod 132 rotates. Stationary ring 136 keeps guide rod 132 in position while it is rotated so that insert support 126 is raised and lowered instead of guide rod 132. Support 144 retains anchors 146 that hold stationary rings 136 and that support housing support 122. Synchronized rotation of guide rods 132 will raise or lower insert support 126 depending on the direction of rotation. Perpendicular raising and lowering of insert support 126 is preferred to ensure that seals 28 and 30 of each reactor 10 engage simultaneously when each insert 16 of support 126 is lowered into its corresponding housing 12-receptacle 22 combination. If surface 128 fails to remain parallel to surface 124 not every reactor 10 of array 120 may seal and/or pinching or binding of seals 28 and 30 within their corresponding reactors 10 could may cause inserts 16 to stick within their corresponding housings 12. Guide rods 132, guide rings 134 and stationary rings 136 are available as catalog numbers S 151101900, S 151201023, S 150600010 and S 159111020 from Rexroth Bosch Group.

[0115] Array 120 can also reduce the need for reservoirs to store feed liquids and gases for reactors 10. One liquid feed reservoir 150 and one gas feed reservoir 152 can respectively introduce liquid and gas feed to reactors 10 if they perform the same reaction with the same liquid and gas feeds. Reservoir 152 may also supply diluent gas if it is the same gas as the gas feed otherwise a third reservoir may supply diluent gas to array 120.

[0116] Each individual reactor of array 120 uses sampling and analysis of the product from each product conduit 40 to evaluate catalysts, usually by determining their activity and selectivity. Analyzers 112 can use the previously described analytic techniques to determine composition and other properties for samples recovered from conduits 40.

[0117] Array 120 may also use a reaction heater 108 of the type and in the same manner as previously described. Although FIG. 6 shows array 120 with single reaction heater 108 for all reactors 10, each reactor 10 may alternately have its own reaction heater 108 so that different reactors 10 in array 120 may be kept at different temperatures or multiple reactors may receive heat from multiple heaters.

D. Process of Evaporating and Reacting in an Array of Reactors

[0118] The process of vaporizing liquid feed and reacting the resulting vapor in the presence of catalyst 24 within each reactor 10 of array 120 tracks the process described for the individual reactors 10 and is the same except as otherwise described. For the array120 the liquid feed enters each multiple evaporation zone 18 simultaneously through injectors 48 so that reactors 10 of array 120 operate in parallel. The evaporator heater 20 provides the heat for the multiple reactors 10 in array 120. Generated vapor and other feed components pass through fluid permeable members 80 and into reaction zone 26 having a temperature controlled by a single reaction heater 108 or multiple reaction heaters 108. Multiple thermocouples 54 monitor the temperature of catalyst 24 in each reaction zone 26 to control the setting of the single or multiple reaction heaters 108. Diluted or undiluted product gas streams emanate from the reactors 10 through product conduits 40 for sampling and analysis of chemical composition to determine activity, feed conversion, major product and byproduct selectivities and yields for each catalyst 24.

[0119] Several advantages of the present invention are readily apparent. The evaporation zone is versatile because it allows liquid phase feeds to be fed as a gaseous fluid to a variety of different types of treatment zones. Feeds of different phases may be mixed and fed as a gaseous mixture to the treatment zone. For example, a liquid phase feed may be vaporized and combined with a gas phase feed to form a continuous supply of a gaseous mixture. With both the evaporation zone and the treatment zone located in the same process vessel any need to transport the gaseous feed through heat-traced

conduits has been eliminated thereby minimizing the possibility of feed components condensing out of the gaseous mixture prior to encountering the treatment zone. In particular, the inventive evaporation zone can be located within a process vessel that can be easily and quickly assembled and disassembled using seals. The vaporization of the liquid feed is accomplished without compromising the seals that allow the process vessel to be easily assembled.

CLAIMS:

1. A process vessel for evaporating a liquid feed and treating the resulting vapor comprising:

   an evaporation zone;

   an injector defining an orifice for delivering a liquid feed to the evaporation zone;

   at least one evaporation surface having at least a portion positioned with respect to the orifice to deliver liquid to the evaporation zone without the formation of droplets and a portion providing a surface in the evaporation zone for generating vapor;

   a treatment zone in fluid communication with the evaporation zone for receiving vapor therefrom; and

   at least one heater for delivering heat to at least a portion of the evaporation surface.

2. A process vessel according to claim 1 comprising one of an array of process vessels for evaporating a liquid feed and treating the resulting vapor in combinatorial processes.

3. A process vessel according to claims 1or 2 wherein a gap formed between the orifice and the evaporation surface is smaller than a predicted diameter of a droplet forming at the orifice.

4. A process vessel according to any of claims 1-3wherein the injector extends into the evaporation zone and defines the orifice therein.

5. A process vessel according to any of claims 1-3 wherein the evaporation surface is selected from the group consisting of a porous monolith, a plate, a cone, packing and combinations thereof.

6. A process vessel according to any of claims 1-3 wherein the evaporation zone has an inside diameter, the evaporation zone contains a bed of packing material comprising discrete particles and the particles have a maximum diameter less than or equal to 10% of the inside diameter of the evaporation zone and a minimum diameter at least as great as the diameter of the orifice.

7. A process vessel according to any of claims 1-3 wherein a first heater primarily delivers heat to the evaporation zone and a second heater primarily delivers heat to the treatment zone.

8. A process vessel according to any of claims 1-3 wherein a product conduit recovers the treatment effluent as product from the treatment zone and a diluent gas inlet delivers diluent to the treatment gas effluent.

9. A process for vaporizing a liquid feed and treating the resulting vapor comprising:

injecting a liquid feed through an injector having an orifice into a process vessel having a housing encasing an evaporation zone and a treatment zone wherein the liquid feed enters the process vessel at conditions promoting the formation of liquid droplets at the orifice;

positioning the injector orifice and at least a portion of an evaporation surface to provide a predetermined gap therebetween to prevent the formation of a liquid drop of the injected liquid feed at the orifice;

heating the liquid feed so that it will be at least at its bubble point while it is in contact with the evaporation surface to generate a vapor;

flowing the vapor to the treatment zone; and

treating the vapor within the treatment zone to generate an effluent.

10. The process according to claim 9 wherein a plurality of liquid feeds pass each pass separately through an orifice of one of a plurality of injectors into a separate process vessel to generate a separate effluent from a treatment zone for each liquid feed.

11. The process according to claim 9 or 10 further comprising injecting each liquid feed through an orifice located within the evaporation zone.

12. The process according to claim any of claims 9 - 11 further comprising mixing the vapor with a gas feed within one or more evaporation zones.

13. The process according to claim 12 further comprising analyzing the one or more of the effluents.

14. The process according to claim 12 further comprising diluting the one or more of the effluents.

15. The process according to claim 12 further comprising selecting the evaporation surface from the group consisting of a bed containing packing, a porous monolith, a plate, a cone, and combinations thereof.

16. The process according to claim 15 further comprising positioning the orifice and the packing so that the gap is smaller than a predicted diameter of a liquid droplet forming at the injector orifice.

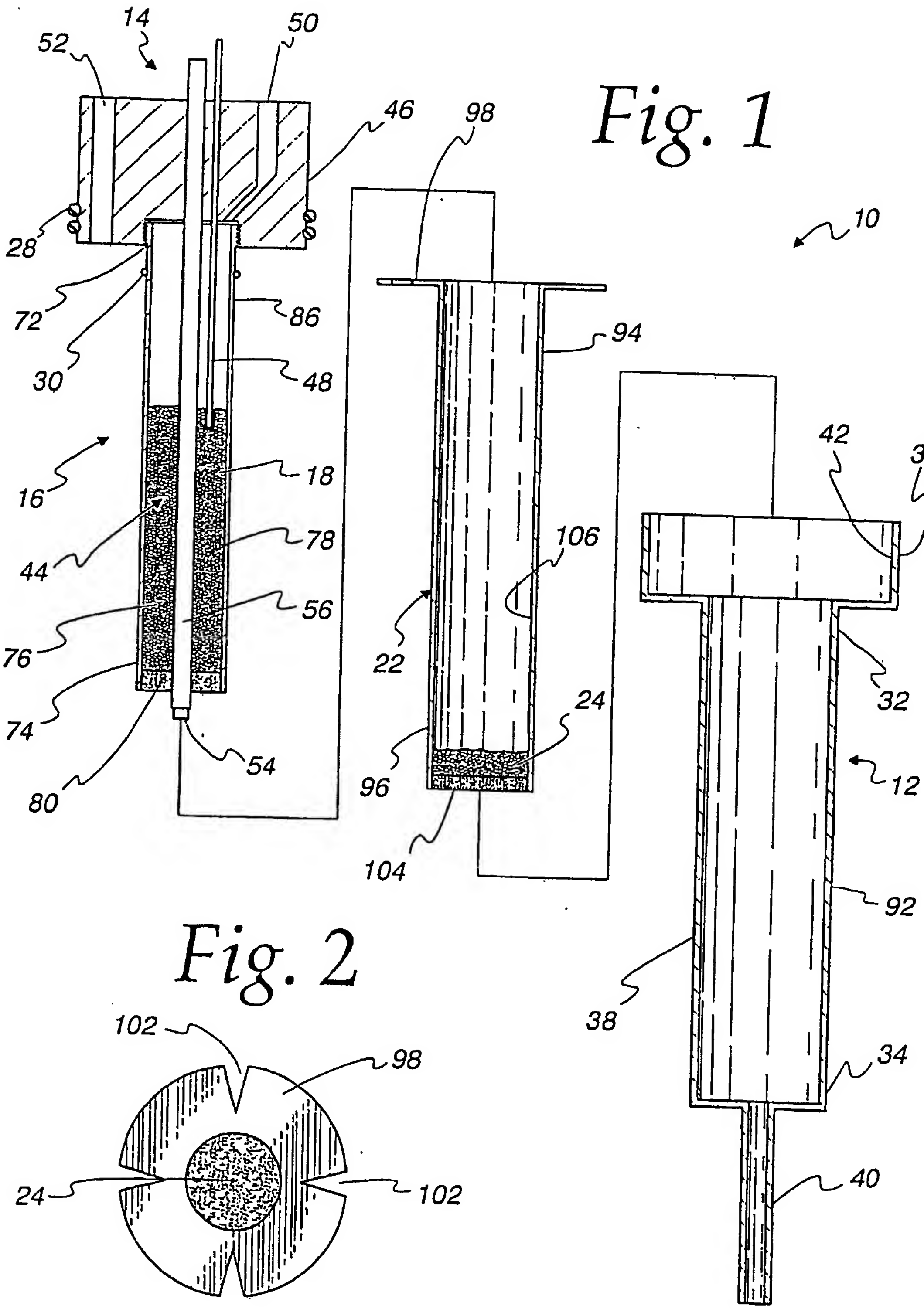
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Fig. 1

Fig. 2

Fig. 3

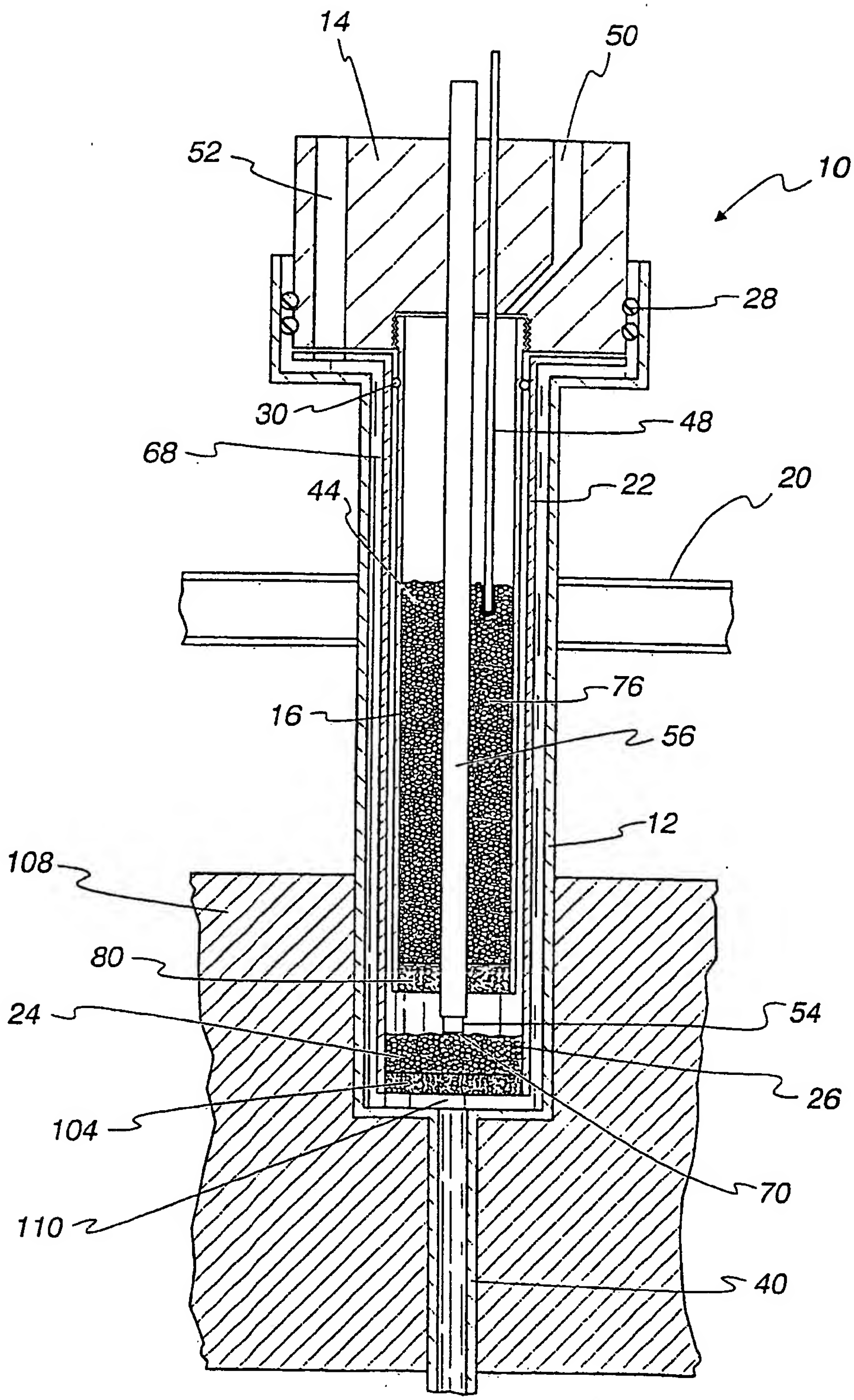
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Fig. 4

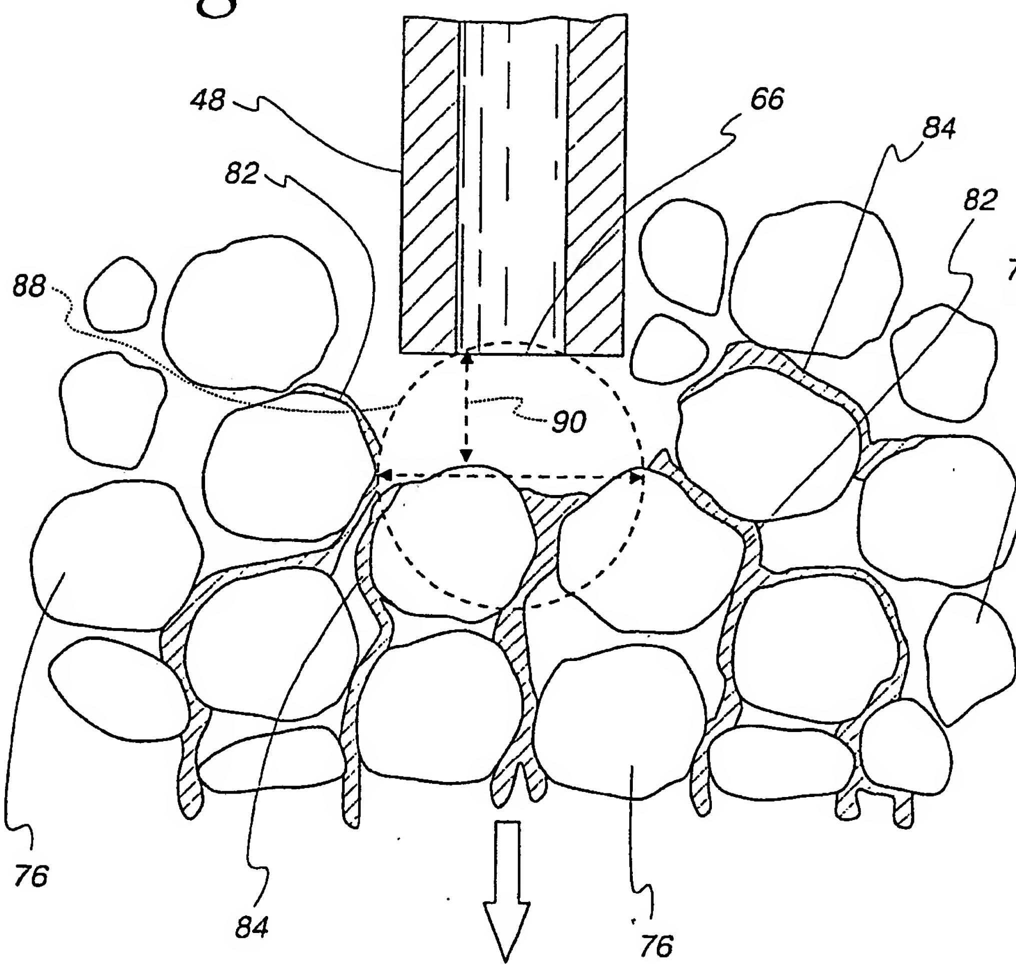
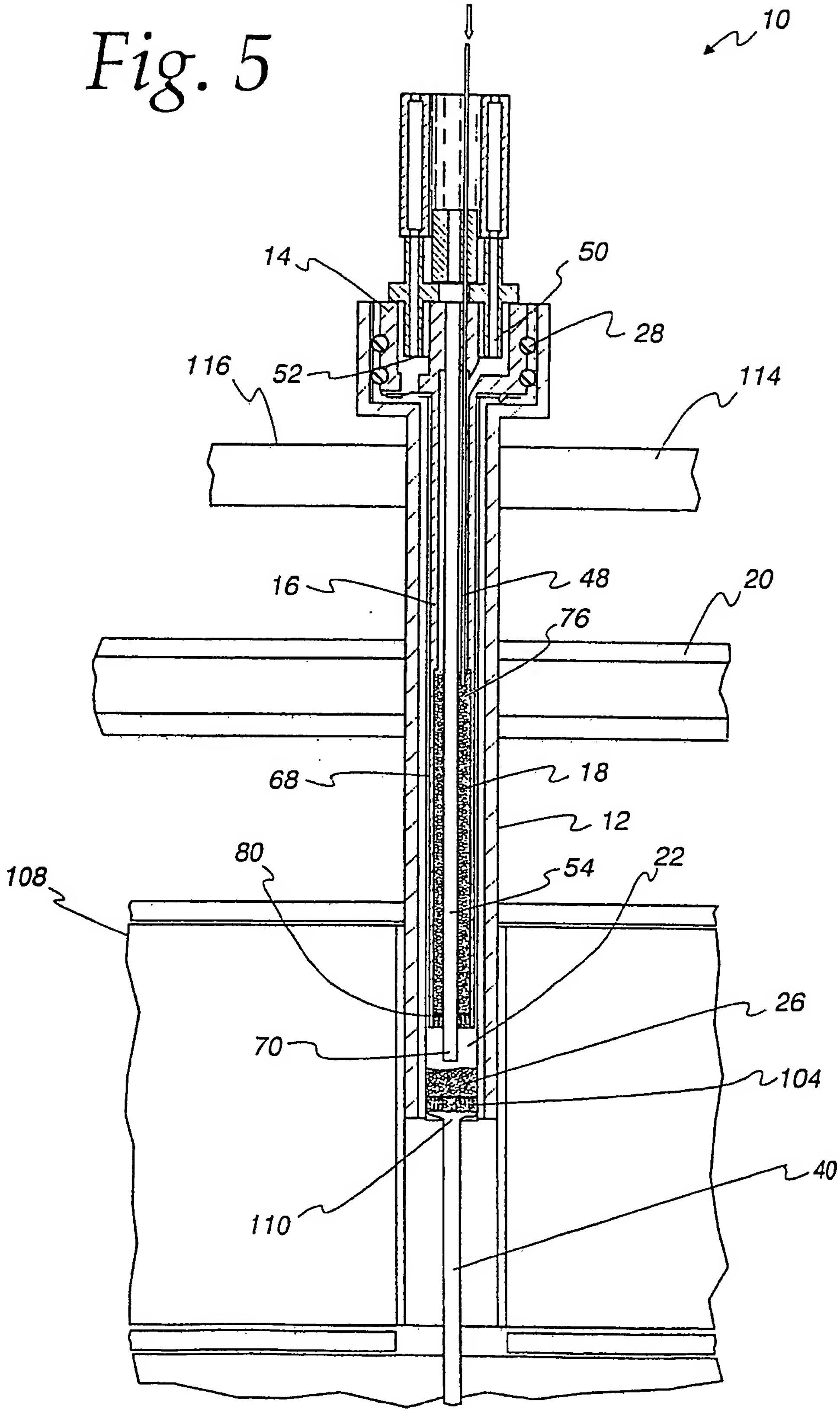


Fig. 5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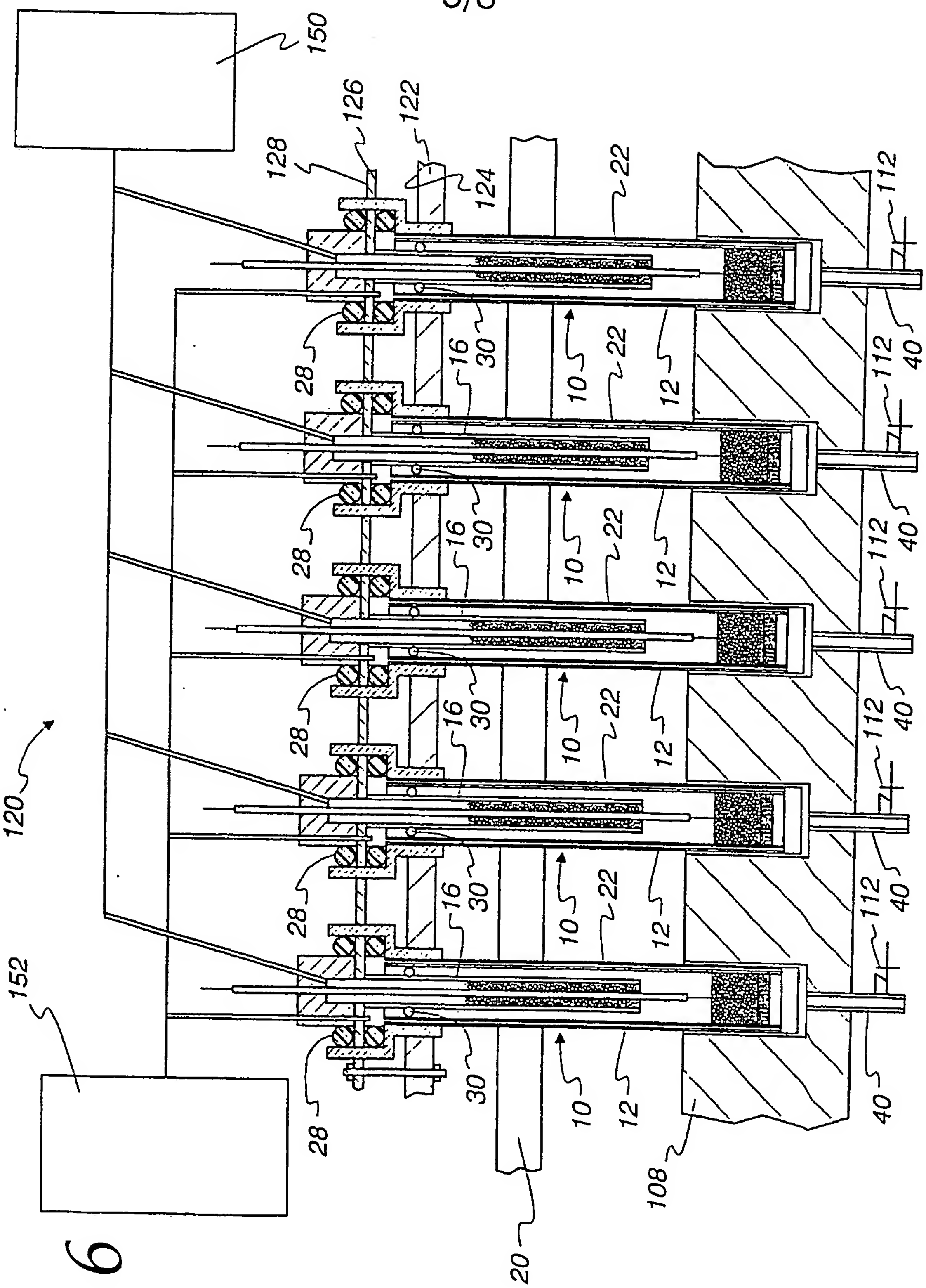

Fig. 6

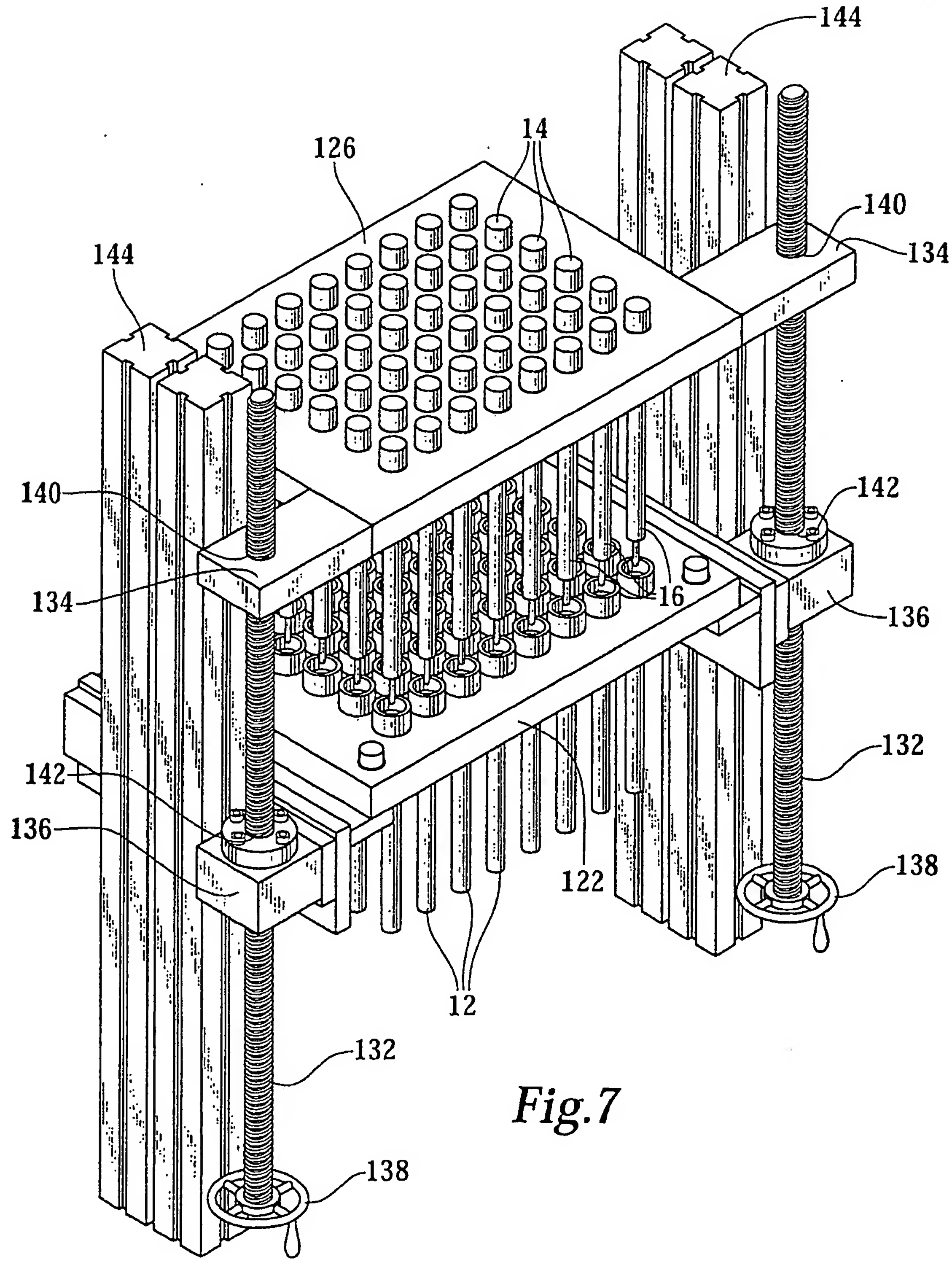
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Fig.7

INTERNATIONAL SEARCH REPORT

PCT/US 03/08228

A. CLASSIFICATION OF SUBJECT MATTER

IPC 7 B01J19/00 B01J8/02 B01J8/06 B01J8/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 A61K B01J G01N B01D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 861 802 A (ENGINEERING ADVANCEMENT ASS OF ;MITSUBISHI ELECTRIC CORP (JP)) 2 September 1998 (1998-09-02) abstract column 6, line 54 -column 7, line 31 column 18, line 2 -column 21; figures 1,5	1,5,7,9, 10,13,15
X	US 5 453 256 A (RUMPF GUENTER ET AL) 26 September 1995 (1995-09-26) abstract column 1, line 6 - line 16 column 2, line 39 -column 3, line 42; figure	1-16

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
23 July 2003	31/07/2003
Name and mailing address of the ISA European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Authorized officer Nazario, L

INTERNATIONAL SEARCH REPORT

PCT/US 03/08228

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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A	WO 01 44801 A (DAHL IVAR M ;KARLSSON ARNE (NO); WENDELBO RUNE (NO); AKPORIAYE DUN) 21 June 2001 (2001-06-21) the whole document	1-8
A	EP 1 108 467 A (UOP LLC) 20 June 2001 (2001-06-20) the whole document	1-8
A	DE 198 09 477 A (SCHUETH FERDI) 16 September 1999 (1999-09-16)	

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